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A CASE STUDY ON APPLICATIONS OF HEAT PUMP IN INDIA

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ABSTRACT

The 21st century is facing huge problems of energy crisis. Due to this, there are advancements in almost every field of engineering. One of that field which has great importance is Refrigeration and Air conditioning. A heat pump is a device that provides heat energy from a source of heat or 'heat sink' to a destination. Heat pumps are designed to move thermal energy opposite to the direction of spontaneous heat flow by absorbing heat from a cold space and releasing it to a warmer one. This paper comprises of detailed case study about reversible heat pumps and their different types along with applications. Geothermal heat pump is one of the recent innovations that have been being researched on large scale in European countries. India is one of the largest market for heat pumps. Taking this criterion into consideration, case study is explained along with results which shows how efficient are the heat pumps.

Keywords-Heat Sink, Geothermal Heat Pump, COP

I. INTRODUCTION

A heat pump uses some amount of external power to accomplish the work of transferring energy from the heat source to the heat sink.

While air conditioners and freezers are familiar examples of heat pumps, the term "heat pump" is more general and applies to many HVAC (heating, ventilating, and air conditioning) devices used for space heating or space cooling. When a heat pump is used for heating, it employs the same basic refrigeration-type cycle used by an air conditioner or a refrigerator, but in the opposite direction - releasing heat into the conditioned space rather than the surrounding environment. In this use, heat pumps generally draw heat from the cooler external air or from the ground. In heating mode, heat pumps are three to four times more efficient in their use of electric power, than are simple electrical resistance heaters.

Heat spontaneously flows from warmer places to colder spaces. A heat pump can absorb heat from a cold space and release it to a warmer one. "Heat" is not conserved in this process, which requires some amount of external high grade (low-entropy) energy, such as electricity.

Heat pumps are used to provide heating because less high-grade energy is required for their operation than appears in the released heat. Most of the energy for heating comes from the external environment, and only a fraction comes from electricity (or some other high-grade energy source required running a compressor). In electrically powered heat pumps, the heat transferred can be three or four times larger than the electrical power consumed, giving the system a coefficient of performance (COP) of 3 or 4, as opposed to a COP of 1 for a conventional electrical resistance heater, in which all heat is produced from input electrical energy.

Heat pumps use a refrigerant as an intermediate fluid to absorb heat where it vaporizes, in the evaporator, and then to release heat where the refrigerant condenses, in the condenser. The refrigerant flows through insulated pipes between the evaporator and the condenser, allowing for efficient thermal energy transfer at relatively long distances.The main disadvantage is the higher initial capital cost, being about 33% more expensive than air source units [8].Capacity controlled heat pumps are gaining increased market share and provide high flexibility in operation. The possibility to use thermal storage to decouple thermalproduction and electric load from the heat pump can be used for operation strategies, hereby increasing the possibility to integrateelectricity production from renewable energy sources [1].

II. REVERSIBLE HEAT PUMP

Reversible heat pumps work in either thermal direction to provide heating or cooling to the internal space. They employ a reversing valve to reverse the flow of refrigerant from the compressor through the condenser and evaporation coils.

In heating mode, the outdoor coil is an evaporator, while the indoor is a condenser. The refrigerant flowing from the evaporator (outdoor coil) carries the thermal energy from outside air (or soil) indoors, after the fluid's temperature has been augmented by compressing it. The indoor coil then transfers thermal energy (including energy from the compression) to the indoor air, which is then moved around the inside of the building by an air handler. Alternatively, thermal energy is transferred to water, which is then used to heat the building via radiators or under floor heating. The heated water may also be used for domestic hot water consumption. The refrigerant is then allowed to expand, cool, and absorb heat to reheat to the outdoor temperature in the outside evaporator, and the cycle repeats. This is a standard refrigeration cycle, save that the "cold" side of the refrigerator (the evaporator coil) is positioned so it is outdoors where the environment is colder. In cold weather, the outdoor unit is intermittently defrosted by briefly switching to the cooling mode. This will cause the auxiliary or Emergency heating elements (located in the air-handler) to be activated. At the same time, the frost on the outdoor coil will quickly be melted due to the warm refrigerant. The condenser/evaporator fan will not run during defrost mode.

In cooling mode the cycle is similar, but the outdoor coil is now the condenser and the indoor coil (which reaches a lower temperature) is the evaporator. This is the familiar mode in which air conditioners operate.

2.1 Operating Principles

Mechanical heat pumps exploit the physical properties of a volatile evaporating and condensing fluid known as a refrigerant. The heat pump compresses the refrigerant to make it hotter on the side to be warmed, and releases the pressure at the side where heat is absorbed.

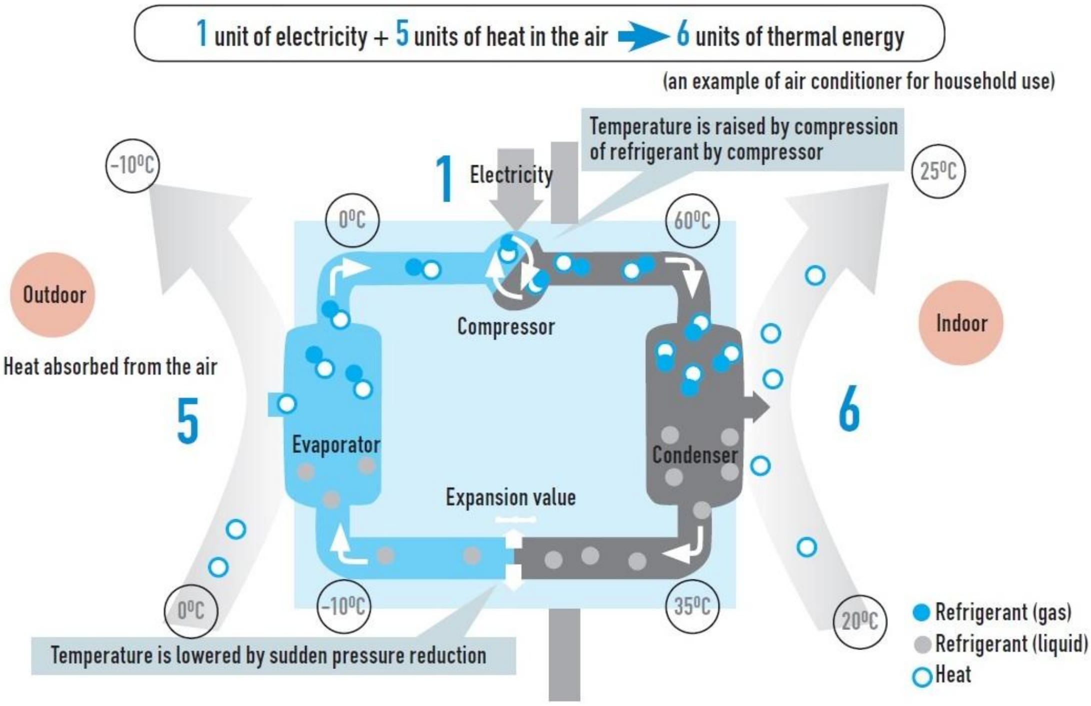


Image 1: Heat pump cycle[9]

The working fluid, in its gaseous state, is pressurized and circulated through the system by a compressor. On the discharge side of the compressor, now hot and highly pressurized vapor is cooled in a heat exchanger, called a condenser, until it condenses into a high pressure, moderate temperature liquid. The condensed refrigerant then passes through a pressure-lowering device also called a metering device. This may be an expansion valve, capillary tube, or possibly a work-extracting device such as a turbine. The low pressure liquid refrigerant then enters another heat exchanger, the evaporator, in which the fluid absorbs heat and boils. The refrigerant then returns to the compressor and the cycle is repeated.

It is essential that the refrigerant reaches a sufficiently high temperature, when compressed, to release heat through the "hot" heat exchanger (the condenser). Similarly, the fluid must reach a sufficiently low temperature when allowed to expand, or else heat cannot flow from the ambient cold region into the fluid in the cold heat exchanger (the evaporator). In particular, the pressure difference must be great enough for the fluid to condense at the hot side and still evaporate in the lower pressure region at the cold side. The greater the temperature difference, the greater the required pressure difference, and consequently the more energy needed to compress the fluid. Thus, as with all heat pumps, the coefficient of performance (amount of thermal energy moved per unit of input work required) decreases with increasing temperature difference.

Insulation is used to reduce the work and energy required to achieve a low enough temperature in the space to be cooled.To operate in different temperature conditions, different refrigerants are available. Refrigerators, air conditioners, and some heating systems are common applications that use this technology.

Solar district heating (SDH) with seasonal thermal energy storage (STES) is a technology to provide heat for space heating and domestic hot water preparation with a high fraction of renewable energy. In order to improve the efficiency of such systems heat pumps can be integrated [15].

2.2 Efficiency

When comparing the performance of heat pumps, it is best to avoid the word "efficiency", which has a very specific thermodynamic definition. The term coefficient of performance (COP) is used to describe the ratio of useful heat movement per work input. Most vapor-compression heat pumps use electrically powered motors for their work input. However, in many vehicle applications, mechanical energy from an internal combustion engine provides the needed work.

According to the US EPA, geothermal heat pumps can reduce energy consumption up to 44% compared with air-source heat pumps and up to 72% compared with electric resistance heating. Heat pumps in general have a COP of 4.2 to 4.6 which places it behind cogeneration with a COP of 9.

The COP for a heat pump in a heating or cooling application, with steady-state operation, is:

$$COP_{\text{heating}} = \frac{\Delta Q_{\text{hot}}}{\Delta A} \leq \frac{T_{\text{hot}}}{T_{\text{hot}} - T_{\text{cool}}},$$

$$COP_{\text{cooling}} = \frac{\Delta Q_{\text{cool}}}{\Delta A} \leq \frac{T_{\text{cool}}}{T_{\text{hot}} - T_{\text{cool}}},$$

Where,

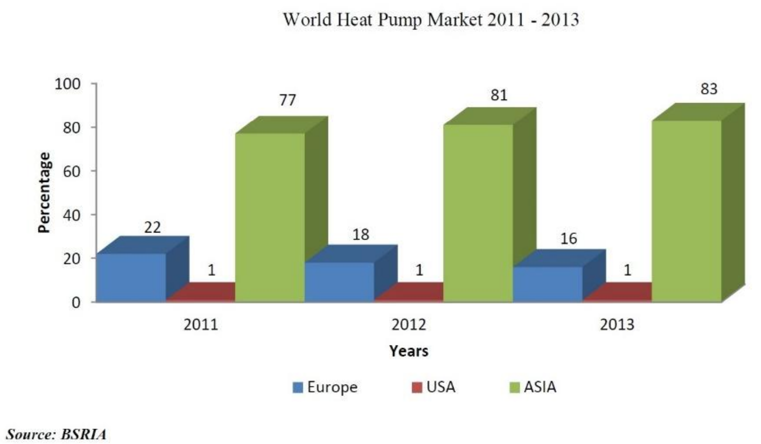
- Q_{cool} is the amount of heat extracted from a cold reservoir at temperature,
- Q_{hot} is the amount of heat delivered to a hot reservoir at temperature,
- A is the compressor's dissipated work.
- All temperatures are absolute temperatures usually measured in Kelvin or degrees Rankin.

III. APPLICATIONS

From application point of view, basic application of heat pump is space conditioning. It operates on basic principle of refrigerating cycle.But now-a-days, the heat pump is extensively used for multiple purposes or to serve multiple functions.Heat pumps are extensively used also for liquid conditioning. Application of heat pumps in hotels, malls, theatres is growing in a country like India. Taking this growth into consideration, it is needed to boost the research in this field. In India, tremendous amount of solar energy is available. The system combination of solar thermal collectors and heat pumps is a very attractive option for increasing the renewable energy usage at worldwide level for heating and domestic hot water preparation [11].

In hotels, malls, etc. water is needed for both hot and cold applications. This application can be commonly implemented with the help of heat pump. The basic methodology is based on refrigeration and heating results which will be calculated with the help of temperatures obtained by different thermometers. Using water as secondary refrigerant, theory claims that efficiency increases by 30%. RefrigerantR-134a is used as refrigerant which has lowest temperature of -27^{o}C and highest temperature as +72^{o}C. ½ horse power compressor will be enough to complete refrigeration cycle efficiently.The above mentioned systems are currently being used at various malls, multi starred hotels, restaurants like KFC's and McDonald's, etc.

Philip D. Fairchild saw a bright future for heat pump applications way back in 1981. Looking ahead to the residential and commercial space conditioning needs of the future, it is apparent that heat pumps will play an important role in this energy use sector. This is emphasized by the remarkable growth in sales of electric air-to air heat pumps during the past few years and the extensive heat pump research and development activities [2]. Absorption, adsorption, desiccant systems, ejector-compressor systems are being developed for coupling with thermal heat sources, such as waste heat in cogeneration systems as well as renewable energy sources such as solar, geothermal and biomass. The search for new systems is directed to higher efficiency systems such as double effect or even triple effect systems and in the other hand the use of single stage systems that can operate at even lower firing temperatures than systems available ten years ago [5].



Graph 1: World Heat Pump Market Percent Sales [14]

Hydro-fluorocarbon (HFC) working fluids have been mainly chosen to replace chlorofluorocarbons (CFCs) in refrigeration and air conditioning due to high merits in safety, performance, and no effect on ozone depletion. HFC compounds generally have lower global warming potential values than CFCs, but these values are higher than for fluids such as ammonia, hydrocarbons, and carbon dioxide. To minimize the impact of HFCs on climate change, it is important for industry to continue improving stewardship-in use practices. This includes selection of HFCs for applications with high societal value, and cradle-to grave management of emissions during HFC production, transportation, use, equipment servicing, and final recovery. Refrigeration and air conditioning equipment is being designed and operated for reduced HFC emissions, and with improved energy efficiency for reduced carbon dioxide emissions [4].

The graph describes the growth of heat pump applications in Asia, as the population rise in this part of the world is huge. There is tremendous amount of need for space conditioning systems in distant future. The success rate of heat pumps has grown as the efficiency and reliability of these systems have shown improvements and hazardous gases are also eliminated from use [6].

IV. CASE STUDY

For case study, we chose an application which was useful for maintaining relative humidity along with maintaining temperature. This application was used in food industries, especially for products which are needed all throughout the year. For example, fruits like banana, vegetables like coriander, capsicum, and mushroom are needed throughout the year. These products need to be taken care of at the time when they cannot be cultivated. In order to do so, heat pumps can play an important role.

The case study results are as discussed below. The device is basically a heat pump, which gives good results for both cold and hot side. A cavity was prepared for storage of product which is an insulated chamber to avoid heat dissipation. The temperature maintained here is below zero degree Celsius. Another cavity which is basically a water tank, was given feed of copper pipes which carried hot refrigerant. The temperature achieved here was about 70-80 degree Celsius.

The conventional methods which are currently used for ripening the bananas have drawbacks like weight loss after processing, time consumption, etc. This drawbacks are not seen in this particular model. Also, it is applicable for Mushrooms, Capsicums and Coriander. Coriander is needed all throughout the year and its cost reaches peak when there is no production. Hence, this application will help in storage of such vegetables which will allow farmer to earn well and take some other crops at no production period.

Specifications of heat pump:

1. Compressor: Tecumseh-AWX 2450ZGE - 2 HP
2. Refrigerant: R-404a
3. Hot water tank: 25 liters
4. Cold storage capacity: 1200 liters with puff insulation
5. Control panel – RH indicator and Temperature indicator
6. Standard Voltmeter and Ammeter

Sr. No.	**Time (hours)**	**Compressor ON/OFF**	**Fan ON/OFF**	**Temperature Hot**	**Temperature –**	**Voltage (volts)**	**Relative humidity**
1.	0	OFF	OFF	26	18	230	-
2.	¼	ON	ON	38	13	230	89
3.	½	ON	ON	46	-4	230	88
4.	1 ½	ON	ON	54	-9	230	81
5.	2	ON	ON	57	-17	230	76
6.	3	ON	ON	58	-20	230	75
7.	3 ½	ON	ON	59	-21	230	73

Table 1: Results of the Heat Pump used for Case Study

The results in above table show that there is considerable difference between cold and hot temperatures in country like India. Use of different refrigerants and compressor units can improve the results according to requirement. Relative humidity is maintained, hence vegetables and fruits can be stored and allowed for ripening under observations. This results show that heat pumps have great application in agricultural production.

The electricity consumption is also considerably less as compared to conventional methods of space conditioning. Heat pumps for domestic heating and hot water supply are currently a niche technology in many European countries, but they are increasingly expected to form an important role in a low carbon future. This is largely because a future of rapidly decarbonized electricity supply is imagined, in which using electricity via heat pumps is one of the lowest carbon heating options [3].

Image 2-3: Actual working model of heat pump

Images shown above show actual model on which case study was carried out. Cold storage space is basically insulated freezer designed to avoid heat dissipation to high extent. It has two doors of size 2'2"*2'2" on the upper side. This prototype is specially made for maintaining relative humidity which is needed for storage of Mushrooms.The results obtained are good enough for healthy storage of fruits and vegetables. Thus, use heat pumps in Indian subcontinent is favourable and profitable when used for commercial and mass applications.

V. CONCLUSIONS

1. Even though improvements in efficiency and reduction in costs would make heat pumps a more attractive option, these are unlikely to be sufficient factors to drive a transition towards heat pumps in the mainstream.
2. Heat Pumps are currently the most cost-effective form of heating using electricity and most good quality systems achieve average COP (Coefficient of Performance) figures of four or more. This means that to achieve four kilowatts of heating or cooling power, they use an average of less than one kilowatt of electricity.
3. A conventional heating system such as an electric fire or gas boiler has a COP of less than one. This means that it burns more than one kilowatt of power to produce a kilowatt of heating power. The higher the COP the cheaper a heating appliance is to run. In comparison to other forms of heating, Heat Pumps offer the most energy efficient heating with between 300% to 400% efficiency.
4. In the more distant future, after 2030, in theory heat pumps will become a very attractive low carbon option due to the availability of low carbon electricity throughout the world.
5. India, which is already a huge market for heat pumps, need a boost in order to increase and develop the applications heat pump in refrigeration and air conditioning industry. Application of heat pump along with solar power can be a great energy option for country like India.

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